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# User-Centred Human-Robot Collaborative Handling of Small Parts in a MIM Process

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**Abstract.** Collaborative technologies can help improve work conditions for operators with any profile, in demanding production tasks. This paper presents an intervention in an intermediate stage of a Metal Injection Molding (MIM) manufacturing process with poor ergonomics, both physical and stress-related, due to sustained visual attention demands. A collaborative workstation was designed and implemented, integrating a collaborative robot and a machine-vision system for bin-picking. The strategy of the intervention was to distribute tasks between worker and robot, where the robot undertook the non-ergonomic task of arranging small pieces close together on a plate, forming a pre-established pattern. Tests with a first implementation suggest that the task-sharing intervention for the manipulation of small MIM-produced references is viable. Careful design of robot fingers is key for the manipulation of such parts, and ambiguous piece configurations require fine tuning of visual piece identification systems, for error-free execution.

**Keywords.** collaborative robot, bin picking, metal injection molding, accessibility

## 1. Introduction

Manufacturing research has traditionally focused primarily on the improvement of processes, from productivity and quality perspectives. However, objectives with a social angle have also come to the forefront as manufacturing technologies have advanced.

In recent years, collaborative manufacturing technologies have reached sufficient readiness to be integrated in collaborative manufacturing cells, to make them more flexible and accessible. The workstations designed in the CMT4ALL project[2] are an example of this, providing lower access barriers to manufacturing jobs and better work conditions for workers with any profile, while also supporting performance (like in [5]). This paper describes one of such workstations being produced in the project.

An intervention with collaborative technologies is presented for the improvement of ergonomic conditions in a Metal Injection Molding (MIM) production process. The resulting scenario is one of synchronized cooperation between human and robot [2], where both human and robot share a part of the workspace to complete a manufacturing task in a joint effort.

The solution is centered around the design and deployment of a collaborative workstation, integrating two technologies that are undergoing significant advancement

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in recent years, with increasing adoption for industrial applications: a collaborative robot [6] and a machine-vision-enabled bin-picking solution [1, 3].

## 2. Production scenario and intervention requirements

Metal (powder) Injection Molding (MIM) is a process that relies on shaping metal particles and subsequently sintering those particles [4]. The process is best suited to produce large numbers of small pieces (up to 120gr per part) with complex geometries and offering high mechanical performance.

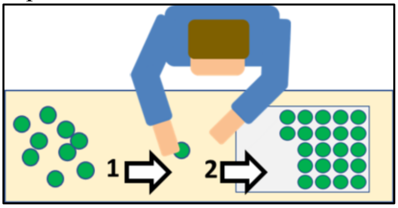


**Figure 1**. Before the intervention, two-step task carried out on each piece by the operator. *Step-1*: visual inspection of piece and deburring of injection defects. *Step-2*: arranging pieces on a plate.

The intervention reported here was made in a two-step stage of the original layout in a MIM process. Both steps are originally carried out by a single worker (Figure 1). In the *first step*, the worker inspects each piece visually and deburrs injection defects from it. In the *second step*, the worker places the deburred piece on a plate, carefully arranged on a predefined pattern (specific of each reference). See example in Figure 2.

**Figure 2.** Example of a reference (L·W·D = 46·10·5 mm approx.). 108 pieces arranged on a 6x18 matrix pattern, on a plate with dimensions (approximate) 206x305mm. No physical contact between pieces.

### 2.1. First step: visual inspection and deburring

In the first step, the worker inspects each piece visually and removes burrs from it. Workers with a wide range of profiles can carry out this task efficiently and comfortably.

### 2.2. Second step: arranging pieces on a plate

In the second step, the worker places each deburred piece on a plate, carefully arranged in the exact position of a predefined pattern (specific for the reference). Respecting position and inter-piece space in the pattern (no two pieces should be left in physical

contact) is a strict requirements, resulting in a densely packed arrangement of pieces. An example of one such pattern is shown in Figure 2.
The second step is much more taxing for the worker. The demands of precision require dexterity and sustained visual attention from the worker, who must stare at the pieces on the plate from a short distance. This often leads to the worker bending over the plate to get a close-up view of the pieces on the plate, leading to back postures poor physical ergonomics. In addition, the frequent and sustained short-distance visual attention demands have shown to be a potential source of stress.

## 3. Design and Implementation of the Collaborative Workstation

The strategy devised to improve the ergonomic challenges (physical and stress related) of the process was to delegate the more taxing part of the process (step-2, arranging each piece on the plate) to a cobot, with the worker still performing step 1 of the task (inspecting and deburring each piece).

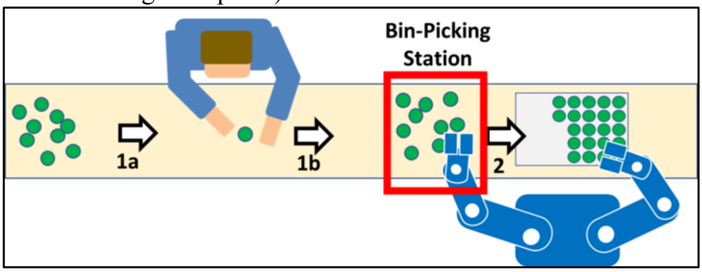


**Figure 3.** After the intervention, the two-step task is carried out collaboratively between worker (Step-1, inspection and deburring) and cobot (Step-2, arranging on plate). See main text for details.

The layout resulting from implementing this strategy is depicted in Figure 3. Like before, after the intervention the worker inspected and deburred pieces one by one (1a). Unlike before, the worker simply left the deburred pieces near the robot (1b) in random positions and orientations (no effort for a neat arrangement was required anymore from the worker). The robot then performed step-2 of the task, by monitoring with machine vision the area of the bin-picking station (Figure 3). If pieces were identified to be processed, the robot performed a bin-picking task of each piece and placed them on the plate, in their required position and orientation to form the pattern.

Depending on the orientation in which a piece was left by the worker, the robot might be able to pick it and place it on the destination plate with a single arm trajectory. However, if that was not possible (e.g., because of the orientation in which the worker had left it), the robot would need to transfer the piece from one hand to the other, rotating it in space before placing it in it required side and orientation.

The following sub-sections discuss in further detail the collaborative robot and the bin-picking machine vision solution integrated in the workstation for the processing of small pieces in the MIM production process.

### *3.1. Collaborative robot*

The collaborative robot selected for the workstation was a two-arm low-payload collaborative robot, with 7 axes per arm (ABB YuMi – IRB 14000). This cobot offers a payload of 500gr and a reach of 559mm per arm. These specifications suit well the application of handling small MIM pieces within the workspace described. First, the small payload of the robot exceeds the requirements for the handling of any typical MIM produced part (usually weighing well under 120gm per piece). In addition, having two arms is a requirement to be able to rotate the piece when required, to always place pieces in their correct orientation. Being able to transfer any piece from hand to hand confers the robot versatility to process any reference and create any pattern.

The selected robot has by default a two-finger gripper on each hand, with fingers that are too thick for this application. Since in the MIM process the pieces must be placed very close to each other on the destination plate (while without contact between them), new fingers were designed and produced. The new fingers were machined in aluminum, as a strategy to preserve the payload of the robot. While the bases of the fingers were thick to offer rigidity, their tips were just 0.5mm thick over a length of 4mm. These dimensions proofed useful and functional to construct the patterns of pieces in all the references tested. However, with extended use, the fingertips tended to bend. For that reason, new fingers were produced in which the tip ends were made of steel.

**Figure 4**. Top view of the robot transferring a piece from its left hand to its right hand, to turn it over and place it correctly on the plate. The plate can be seen below the robot's hands. On the righthand side of the image, the bin-picking station contains multiple pieces in random positions, ready to be processed,

## *3.2. Machine Vision*

For the implementation reported here, a machine vision system was deployed above the bin-picking station (Figure 3). The aim of this vision station was to monitor production of deburred pieces made by the worker and to process them with the bin-picking function of the robot. In future, an additional machine vision station will be deployed above the destination plate, to perform quality inspection of the pattern created by the robot.

The bin-picking station consisted of a horizontal stand with a work area on which the worker placed inspected and deburred pieces, randomly. The whole of the bin-picking work area was within the reach of the left hand of the robot. Above that work area, a 3D image sensor was installed on a rigid structured, in a fixed calibrated position with respect to the robot and to the rest of the workstation. The sensor was a 3D fringe projection camera (Photoneo PhoXi 3D Scanner S), which provided a point cloud image of the scene. A software application was created to perform the monitoring and bin picking of pieces. The software application made use of a HALCON library[3] for the three-dimensional processing of the point cloud image.

[3] https://www.mvtec.com/technologies/3d-vision

The surface model of the reference being produced in the MIM process was provided to the application, which included its CAD model and associated grasping points. The application then looked for matches of the surface model in the point cloud, and it granted to each matched set of points a score, rating the goodness of the match. In Figure 5 (left), see the matches for a reference found in the cloud captured from the bin picking station.

Supporting the collaboration between worker and robot, the process of continuously monitoring the bin-picking station for presence of pieces to be processed freed the operator from having to notify the robot explicitly.

The matches that had been found in the point cloud were all candidates to be picked by the robot. The application ranked all candidate matches according to an assigned score that was weighted according to several criteria, such as their position on the z axis, occlusions, and possible collisions of the robot hand and gripper for each of their eligible grasping points. Figure 5 (right) shows an example of the simulation that the application performed to check that, for a selected match and grasp point, the robot's hand or gripper did not lead to a collision with another element in the scene surface model (e.g., another piece, the surface of the work area or any other element in the point cloud). Based on all this, a piece and grasping point was selected and the 6 degrees of freedom for picking were determined and sent to the robot. The robot then calculated trajectories and performed the action of picking.

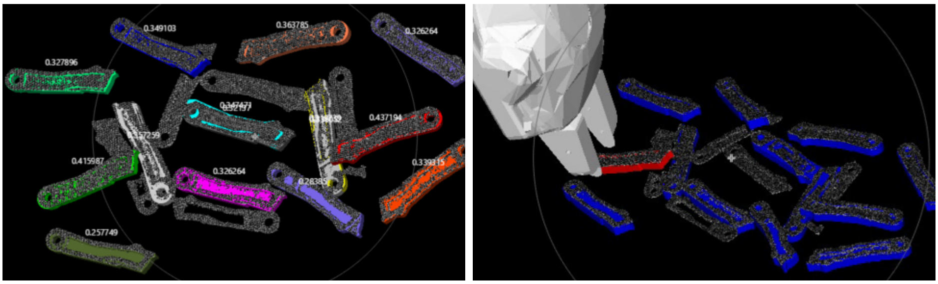

**Figure 5**. *Left:* successful matches of the searched reference in the point cloud. *Right:* in red, the piece selected to be picked (robot hand and gripper test that the selected grasping point is free from collisions).

## 4. First tests and evaluation

An evaluation test was conducted with the first implementation of the workstation, as described above. The objective was to assess its adequacy to process a typical MIM reference, and to identify issues that needed to be improved in future work.

The reference shown in Figure 2 and Figure **4** was selected for the evaluation test. The workstation was required to process 108 units of that reference (from bin-picking to arranging them on the plate) thus creating the complete pattern, as seen in Figure 2.

For the execution of the test, an experiment facilitator placed pieces randomly on the bin-picking station, making sure that (i) pieces overlapped each other on the surface of the bin-picking platform (e.g., as in Figure 5), and that (ii) there were instances of pieces resting upwards and downwards, so that the robot was required to rotate the pieces that were turned downwards by transferring them from hand to hand. As the robot progressed in emptying the bin-picking area, the facilitator added new randomly arranged pieces to the bin-picking area, until all the pieces had been processed and the pattern on the plate was complete. Any events were identified and annotated.

Performance errors were observed in the processing of 7 out of the 108 pieces in the set (6.48% of the total pieces processed). Most observed errors (5 in total) were attributed to a grip of the robot's fingers on the piece that was too slippery and not sufficiently secure. As a result, the piece fell twice while it was being transferred from one hand to the other. In addition, three times the piece fell off the gripper as it was being transported.

Regarding the bin-picking functionality, twice the piece was placed upside down on the plate. This could be explained because both sides of the piece used for the test were very similar, and the mismatch was not sufficiently penalized by the algorithms in the bin picking application. Although this only affected 1.85% of the pieces handled, it showed that such small quasi-symmetrical pieces require additional efforts in the configuration of the identification algorithms, to deliver flawless performance.

## 5. Conclusions and future work

We proposed an intervention with a collaborative workstation (consisting of a collaborative robot and a bin-picking solution) to improve physical and visual attention related ergonomics in a MIM manufacturing process. The strategy of cooperation adopted consisted in delegating on the workstation the more taxing step. An evaluation test with a first implementation suggested that flawless performance will require (i) a new gripper design with better adherence, and (ii) improving point cloud piece matching algorithms in ambiguous piece topologies.

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